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Introduction

Potential Effects of Climate Change on Forest Ecosystems
- Drought
- Fire
- Insect and pathogen damage
- Introduced species
- Extreme weather events
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- Positive effects of climate change on forests

Model Predictions and Regional Climate Change Projections

The Kyoto Protocol and Canada's Commitment to Emissions Reduction

Carbon Sequestration and Storage in Forests to Slow the Effects of Climate Change

Forest Ecosystem Management Options for Nova Scotia

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A Discussion Paper on Climate Change and Forestry in Nova Scotia: Ecological Implications and Management Options

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Introduction:

Climate change resulting from greenhouse gas emissions such as carbon dioxide into the atmosphere is a major global environmental issue facing Canadians (Papadopol, 2000) and may be one of the greatest environmental challenges humanity will face (Pollard, 1989). Despite a number of uncertainties, scientific evidence has lead to a general consensus that climate change is occurring (Albritton *et al.*, 2001). Greenhouse gases trap heat in the atmosphere and emissions have been increasing steadily since the beginning of the Industrial Revolution in the 18th century and atmospheric carbon dioxide levels have increased by 25% since that era (Pollard, 1989; Papadopol, 2000; Parker *et al.*, 2000). Fuel-powered transportation and deforestation for agricultural use have contributed greatly to the increased emissions in recent times (Papadopol, 2000). Some of the more significant greenhouse gases are listed in Table 1 along with their ability to trap heat relative to CO_2 and their lifespan in the atmosphere.

Table 1: Greenhouse gases and a comparison of their relative ability to trap heat in the atmosphere and average lifespan in the atmosphere.

Name of Greenhouse Gas	Relative Ability to Trap Heat	Mean Atmospheric Lifespan (years)
Carbon dioxide (CO_2)	1	5 - 200[1]
Methane (CH_4)	25	8 - 12
Nitrous oxide (N_2O)	250 - 300	110 - 120
Cholorfluorocarbons (CFCs)	4 600 (CFC 11) 10 600 (CFC 12)	45 (CFC 11) 100 (CFC 12)

Source: IPCC, 2001; Papadopol, 2000.

[1] Ranges widely because of different rates of uptake by various processes.

Carbon dioxide (CO_2) is the most abundant greenhouse gas being emitted into the atmosphere and the most significant sources of CO_2 emissions today include: burning of oil and coal (fossil fuels) for use in industry and transportation; domestic heating, which includes combustion of coal, oil, and wood; and deforestation, which includes burning and subsequent exposure of soil, a natural carbon reservoir. Organic matter decomposition contributes to the CO_2 being released. Globally, industrialized countries are responsible for 75% of all CO_2 emissions (IPCC, 2001; Papadopol, 2000) and human activity has a profound influence on climate change (Albritton *et al.*, 2001). Methane (CH_4) is released through anaerobic decomposition of plants and as a by-product of enteric fermentation in animals such as cattle or termites. Nitrous oxide (N_2O) is

emitted through the incomplete use of nitrogenous fertilizers and chlorofluorocarbons (CFCs) are emitted from industrial sources (amounts are declining). Carbon monoxide (CO) is considered an indirect greenhouse gas because it influences the lifetimes of other greenhouse gases in the atmosphere. Carbon monoxide is released through the slow and incomplete burning of biomass (IPCC, 2001; Papadopol, 2000).

Since the end of the 19th century, the global average surface temperature has increased by 0.6°C (± 0.2°C) (Albritton *et al.*, 2001). Depending on the source of information, the average global air temperature increase that will occur with effective doubling the concentration of atmospheric CO_2 ranges from 1°C to 5°C (Canadian Forest Service, 1999; Harrington *et al.*, 1991; Papadopol, 2000; Parker *et al.*, 2000; Pollard, 1989). Canada's average temperatures are expected to increase significantly more than the global average and may be between 5°C - 10°C. However, some areas may experience cooling due to influences from the North Atlantic. Although the averages fall within the range of what is tolerable for most species, the widening of the extreme ends of the spectrum will cause problems. The weather only needs to deviate outside a species' normal range once for that organism to become stressed (Canadian Forest Service, 1999). Increased energy from rising temperatures will increase evaporation at the Earth's surface leading to increases in precipitation between 7.1% and 15.8% globally (Papadopol, 2000; Harrington *et al.*, 1991). This will not be distributed evenly, and some areas will receive large increases while others will experience increased drought. Nova Scotia's forest ecosystems will most likely be impacted by global warming with changes in growth rates, extent of the forest, carbon cycle relationships, species composition, and disturbance regimes (Environment Canada, 1999). Most effects of climate change will increase in magnitude as latitude increases (Harrington *et al.*, 1991; Parker *et al*, 2000).

To gain some insight and perspective on what "a couple of degrees Celsius warmer" could mean for the future of the Earth, Harrington *et al.* (1991) highlighted some interesting statistics. For instance, the warmest average annual temperature during the Holocene post-glacial period (i.e. the last 11 000 years of the Earth's history) was only about 1°C warmer than current temperatures and the coolest mean annual temperature since the ice age was during the Little Ice Age (1570-1820) and was about 1°C colder. The last ice age reached approximately 4°C colder than present average temperatures. An increase in temperature of 2°C above today's average temperature of 15°C, a conservative prediction of what could occur in the next century, would be the warmest mean global temperature the earth has experienced in the last 30 million years. An increase in temperature of 5°C, as some scientists are predicting, would be analogous to a return to the mid-Cretaceous warm period that occurred 80 million years ago. On a positive note, Harrington *et al.* (1991) also reported that there has been a cooling trend globally for the past 3000 years and greenhouse gas emissions may have averted the return of glaciation.

Model Predictions and Regional Climate Change Projections:

General circulation models for climate change are used to predict global and regional effects on air temperature, precipitation, and other variables. However, one must be aware of the uncertainty surrounding the use of current general circulation models due to limitations on the availability of accurate and sufficient computer resources and knowledge of climate systems and climate change (Hadley Centre, 2000).

Prasad and Iverson (1999-ongoing) presented data for several climate variables using five general circulation models projected for the Eastern United States. These models include GISS, developed by the Goddard Institute for Space Studies (NASA Research Institute, 2002), GFDL, developed by the Geophysical Fluid Dynamics Laboratory (US Dept. of Commerce, 2002), UKMO, developed by the United Kingdom Meteorological Office (Met Office, 2003), CGCM2, developed by the Canadian Centre for Climate Modelling and Analysis (Environment Canada, 2000), and HadCM3, developed by the Hadley Centre for Climate Prediction and Research (Hadley Centre, 2000). The two latter models will be investigated further due to readily available data for Atlantic Canada on the Internet.

The CGCM2 and the HadCM3 are coupled atmosphere - ocean general circulation models (Environment Canada, 2000; Hadley Centre, 2000). Coupled general circulation models are more complex than simple climate models because they consist of an atmospheric general circulation model coupled to an ocean general circulation model. Until these two types of models were coupled, prediction of magnitude and rate of climate change could not be performed. The coupled general circulation model has a relatively coarse level of detail with a resolution of a few hundred kilometres (Hadley Centre, 2000). The atmospheric component of the CGCM2 and the HadCM3 include the effects of greenhouse gases, water vapour, ozone, and soil moisture. The oceanic component of these models include such parameters as water flux, sea ice, and vertical mixing (Environment Canada, 2000; Hadley Centre, 2000).

The CGCM2 model predicts that the annual mean surface air temperature in Nova Scotia will increase by 2°C from the 1971-1990 period (representing the current situation) to the 2041-2060 period (Environment Canada, 2000). The 2°C increase is expected under the IS92a scenario, which is the "business as usual scenario" and assumes a 1% annual increase in atmospheric CO_2 concentration with mid-range economic growth and no reduction in greenhouse gas emissions (Hadley Centre, 2000; Environment Canada, 2000). This scenario implies that the concentration of atmospheric CO_2 more than doubles over the next 100 years.

The general circulation model developed by the Hadley Centre in the United Kingdom, the

HadCM3, projects slightly different predictions for changes in air temperatures for Nova Scotia; however, the HadCM3 projects expectations for the end of the 21st century (30 to 40 years further into the future than the CGCM2) (Hadley Centre, 2000). The HadCM3 projections also use the IS92a "business as usual" scenario. The change in average surface air temperature (1.5 m above the ground) is expected to increase from 1960-1990 to 2070-2100 by 3 to 5°C for Nova Scotia. The seasonal predictions of air temperature change for Nova Scotia, according to HadCM3 projections, are shown in Table 2.

Locally, climate models are being downscaled to a finer resolution than the general circulation models, which are several hundred kilometres (Lines *et al.*, 2003). Lines *et al* (2003) used the Statistical Downscaling Model (SDSM) to downscale climate change scenarios from the CGCM1 (the first coupled general circulation model in Canada) (Environment Canada, 2000). Lines *et al* (2003) projected changes in three climate variables: daily maximum temperature (°C), daily minimum temperature (°C), and total daily precipitation (%) for fourteen sites in Atlantic Canada. These variables were projected from 1961-1990 to three tri-decadal periods: the 2020s (2011-2040); the 2050s (2041-2070); and the 2080s (2071-2100). Lines *et al* (2003) reported the SDSM projections along with CGCM1 projections for the same time periods. For the four sites studied in Nova Scotia (Greenwood, Kentville, Shearwater, and Nappan), the annual average for daily maximum and daily minimum temperature was expected to increase (See Table 2). However, the magnitude of change was greater for the daily maximum temperature with the SDSM and greater for daily minimum temperature with the CGCM1.

Table 2: Predicted seasonal changes in average surface air temperature (in °C) for Nova Scotia from 1960-1990 to 2070-2100 from HadCM3 IS92a (Hadley Centre, 2000), the CGCM1 and the SDSM (Lines *et al.*, 2003).

Season	Region within Nova Scotia	Current Mean Temperature (°C)[1]	Predicted Temperature Increase (°C)		
			HadCM3	*CGCM1*[2]	*SDSM*[2]
Year-round average	All of Nova Scotia	6.6	3 to 5	4.1	4.6
Winter (Dec/Jan/Feb)	Cape Breton	-3.7	2 to 3	4.1	5.3
	Mainland Nova Scotia	-3.1	3 to 5		
Spring (Mar/Apr/May)	Western region	4.7	3 to 5	4.7	3.9
	Rest of Nova Scotia	4.1	2 to 3		
Summer (June/July/Aug)	All of Nova Scotia	16.6	3 to 5	3.9	5.4
Fall (Sept/Oct/Nov)	All of Nova Scotia	8.8	3 to 5	3.6	3.3

[1] Statistics from The Weather Network (2003), including averages from Halifax International Airport, Shearwater, Greenwood, Yarmouth, and Sydney. Cape Breton shows statistics for Sydney and Western Region shows statistics for Yarmouth.

[2] Average temperature was calculated from four study sites in Nova Scotia: Greenwood; Kentville; Shearwater; and Nappan (Lines *et al.*, 2003). The CGCM1 is an earlier version of the Canadian coupled atmosphere - ocean general circulation model (Environment Canada, 2000).

Global changes in precipitation were also predicted using the HadCM3 (Hadley Centre, 2000). Changes in the average annual precipitation (including rainfall and the liquid water equivalent for snowfall) from 1960-1990 to 2070-2100 for Nova Scotia, under the IS92a scenario, indicate a change of -6% to 6% in Northern Nova Scotia. This indicates differences from present conditions could go in either direction, but may lead to drought when accompanied with the expected increase in temperature. A 5% to 14% increase in annual precipitation is predicted for the rest of Nova Scotia with the largest increases occurring in the fall and winter. The seasonal predictions of changes in precipitation for Nova Scotia, according to HadCM3 projections, are shown in Table 3. Precipitation might not change in the spring and summer, but is expected to increase in the fall and winter months. Temperature will determine whether the increase in precipitation will fall as rain or snow.

The SDSM and CGCM1 models both predicted an annual average precipitation increase of 5%. The SDSM projected higher increases than the CGCM1 at Greenwood, Kentville, and Shearwater (except for the 2080 period, where a slightly higher increase was projected with the CGCM1) (See Table 3). In Nappan, the CGCM1 projected an increase in annual precipitation and the SDSM projected a decrease in annual precipitation (Lines *et al.*, 2003).

Table 3: Predicted seasonal changes in average precipitation (in mm) for Nova Scotia from 1960-1990 to 2070-2100 from HadCM3 IS92a (Hadley Centre, 2000).

Season	Region within Nova Scotia	Current Mean Precipitation (mm)[1]	Predicted Change in Precipitation (%)		
			HadCM3	*CGCM1*[2]	*SDSM*[2]
Year-round total	Northern region	1230	- 6 to 6	5	5
	Rest of Nova Scotia	1337.6	5 to 14		
Winter (Dec/Jan/Feb)	Western region	377	5 to 12	2	6
	Rest of Nova Scotia	394	11 to 23		
Spring (Mar/Apr/May)	All of Nova Scotia	315.4	- 6 to 6	18	-8
Summer (June/July/Aug)	All of Nova Scotia	280.4	- 7 to 7	1	8
Fall (Sept/Oct/Nov)	All of Nova Scotia	351.2	5 to 13	-3	12

[1] Statistics from The Weather Network (2003), including averages from Halifax International Airport, Shearwater, Greenwood, Yarmouth, and Sydney. Northern Region shows statistics for Moncton, NB and Western Region shows statistics for Yarmouth.

[2] Average precipitation was calculated from four study sites in Nova Scotia: Greenwood; Kentville; Shearwater; and Nappan (Lines *et al.*, 2003). The CGCM1 is an earlier version of the Canadian coupled atmosphere - ocean general circulation model (Environment Canada, 2000).

The Hadley Centre (2000) reported sea-level changes and sea-ice changes by area and volume with the HadCM3 IS92a from 1960-1990 to 2070-2100. The Atlantic Ocean sea levels surrounding Nova Scotia are expected to rise by 0.4 - 0.6 m by the end of the century due to melting of glaciers and thermal expansion of the ocean. Sea-ice in the Northern Hemisphere is expected to decrease in area by 30 - 40% by the year 2100 and a decrease in volume of 50 - 60% is expected (compared to 2000 levels).

Both the HadCM2SUL and the CGCM1, as described by Dale *et al.* (2001), projected an increase of seasonal severity rating of fire hazard by about 10% for eastern Canada. Flannigan *et al.* (2001) reported an increase in Fire Weather Index for Nova Scotia using a modified version of the Canadian general circulation model.

Iverson and Prasad (1998) have developed a model, DISTRIB, which utilizes regression tree analysis with geographic information systems (GIS) and considers environmental variables such as climate, soils, land use, elevation, and species assemblages. Based on this model, Prasad and Iverson (1999-ongoing) have developed a tree distribution atlas, which models potential geographical distributions of eighty tree species in the Eastern United States for a doubled CO_2

scenario using a number of models including one of the Hadley Centre models and one of the Canadian Climate Centre models. The atlas is useful for mapping possible vegetation distributions and abundances that might follow climate change and how the geographical range of suitable habitat for a species will change based on climate tolerance. Prasad and Iverson (1999-ongoing) emphasized that the atlas shows potential distributions and does not consider migration rates (which are expected to be much slower than the rate of climate change), geographical barriers and fragmentation of landscapes, nor interspecific species competition.

Given the vicinity of Nova Scotia to Maine, the distribution trends mapped on the tree atlas for the Northeastern United States might be similar to what might be expected for Nova Scotia. Prasad and Iverson (1999-ongoing) mapped out each tree species and its importance value, which is an index representing the number of stems and the basal area of the overstory and understory (Figure 1). Using the parameters set by the Hadley model, balsam fir (*Abies balsamea*) and white birch (*Betula papyrifera*) are expected to decrease in importance value in Maine, and some areas of the state will not be suitable habitat for the species. The Canadian Climate model predicts the absence of suitable habitat for balsam fir and white birch in Maine. The importance value for white pine (*Pinus strobus*) is expected to increase in Maine and red maple (*Acer rubrum*) is expected to decrease in importance value, using both the Hadley and Canadian Climate models (Prasad and Iverson, 1999-ongoing).

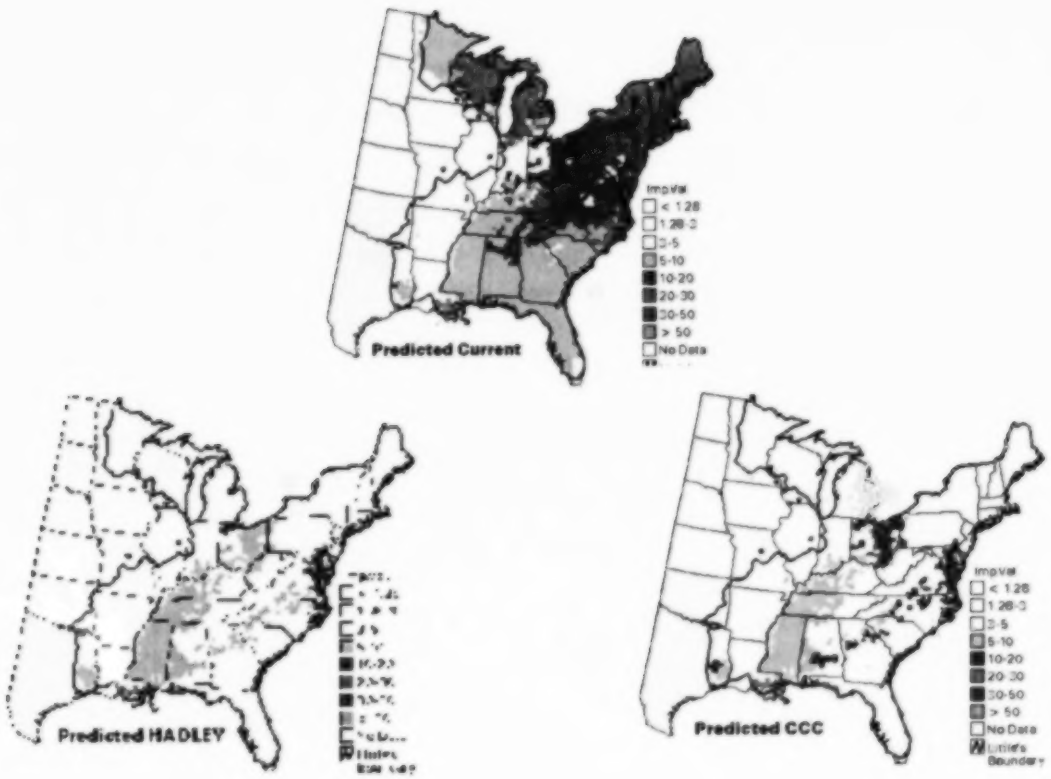

Figure 1: Current and predicted importance values based on the Hadley and Canadian Climate models for red maple (*Acer rubrum*) in the Eastern United States (Prasad and Iverson, 1999-ongoing).

Work is being done in the Maritimes to model tree species distributions based on silvics knowledge and physical environmental data (Bourque *et al.*, 2000). This type of research shows promise for mapping species habitat following climate change by using both silvics knowledge and climate models at a regional scale, similar to the work being done in the Eastern United States (Prasad and Iverson, 1999-ongoing).

Potential Effects of Climate Change on Forest Ecosystems:

Forest ecosystems are complex with many interdependent species. Changing just one environmental variable can lead to numerous direct effects to the ecosystem, which then lead to many more indirect changes. The potential effects of climate change on Nova Scotia's forests are substantial and the magnitude of disorder it might cause within forest ecosystems will depend on the rate and extent of climate change (Pollard, 1989). Although optimal habitat for many species will likely shift to the north, migration will not be uniform and new ecosystems with new species mixes are expected (Canadian Forest Service, 1999; Government of Canada, 2001). Local responses to climate change will depend on site characteristics and physical geography, forest composition and age-class structure, and disturbance and management history. Although local species extinctions might occur, global warming will more commonly increase the stress of some species, affecting overall health. Natural responses to stress involve adaptation. This will occur naturally and can be assisted as well. Generally, a younger-aged forest structure is expected (Government of Canada, 2001). The most noticeable effects of climate change on the forest will be due to changes in weather extremes and forest disturbances (Parker *et al.*, 2000).

Drought:

With an increase in temperature, periods of drought are expected and could contribute to the death of vegetation intolerant to moisture stress, thus leading to an increase in barren area if drought-tolerant species do not inhabit the space (Papadopol, 2000). Moisture stress reduces forest health and increases susceptibility to fires. In response to drought, plants immediately reduce net primary production and water use, which leads to death under prolonged conditions (Dale *et al.*, 2001).

Fire:

Following drought, the risk of increased forest fire frequency and severity is significant (Papadopol, 2000; Dale *et al.*, 2001). Despite fire suppression efforts in Canada, fire still occurs and 97% of the area burned by forest fires is caused by only 3% of all fires (Flannigan *et al.*, 2001). The initiation of forest fires is dependant on dry conditions, the presence of ignition agents, and other conditions such as lightning, wind velocity, and fuel availability (Dale *et al.*, 2001). Increased fuel amounts on the forest floor in declining stands, from insect, disease, or hurricane damage make these forests more vulnerable to fire ignition (Parker *et al.*, 2000). Fire alters a forest ecosystem by accelerating nutrient cycling and altering the carbon balance in the forest, increasing tree mortality, changing stand dynamics and succession, and affecting reproductive tissues and seed banks. Forest value is also altered after fire by loss of wildlife

habitat, timber, and recreation potential (Dale *et al.*, 2001; Flannigan *et al.*, 2001). Amiro *et al.* (2002) reported the possibility of a positive feedback system where increased greenhouse gas emissions, some of which are released by fires (CO_2, methane, and nitrogen oxides), contribute to climate change, which increases the likelihood of additional fires. On the other hand, the Canadian Forest Service (1999) reports a possibility for a less severe fire risk in eastern Canada.

Insect and pathogen damage:

Insects and pathogens generally have a narrow range of thermal tolerance (Papadopol, 2000). Climate affects the survival and reproductive rates of pathogens and insects as well as their geographical distribution (Dale *et al.*, 2001). A warmer climate could accelerate the development of insects, and hence reproductive age, leading to more generations per year of some species (Papadopol, 2000) and milder winters in Nova Scotia might prevent pests from dying back if there is an insufficient period of very cold days (i.e. -25°C) to provide effective control. For Nova Scotia, optimal habitat for Balsam Woolly Adelgid might occur as a result of warmer winters (Environment Canada, 1999). This might lead to widespread tree damage and death (Dale *et al.*, 2001; Pollard, 1989). Typically, insects migrate at a higher rate than trees, therefore it is expected that northern forests will be exposed to non-native herbivores as they migrate from the south. Changes in temperature and precipitation may also indirectly affect the natural regulation of insects and pathogens in the forest by altering the presence of competitors and predators, whose survival is also dependant on climate (Dale *et al.*, 2001). This will leave some areas more vulnerable to attack, and some areas will experience reduced effects from insects and disease. Forests in declining health from climate stresses are more vulnerable to insect and pathogen attacks leading to further instability in the forest.

Introduced species:

Introduced species play many roles in the forest, including: herbivory, predation and competition, alteration of habitat, pathogens or vectors for disease, and alteration of gene pools by hybridizing with native species. Possible outcomes of species introductions include: changes in native species diversity, nutrient cycling, fire frequency, and forest succession, as well as interactions with human activity such as harvesting and managing forests. Climate affects potential exotic species by changing the distribution of the species' optimal habitat for survival and development. Increased CO_2 can also influence introduced plants by altering the rate of photosynthesis and native species' ability to resist herbivory (Dale *et al.*, 2001). Climate change may also favour the fast growth of opportunistic species (both introduced and native) (Pollard, 1989).

Extreme weather events:

Hurricanes are important agents of forest disturbance in Nova Scotia (Neily *et al.*, 2003). As a result of climate change, hurricane frequency, duration, and intensity might increase due to increases in ocean temperature. Hurricanes increase tree mortality, affecting forest structure and composition, dead wood dynamics, and regeneration patterns, which lead to changes in succession and species turnover (Dale *et al.*, 2001). Stand density and tree height affect a stand's susceptibility to hurricane damage (Natural Resources Canada, 2002).

Changes in small-scale windstorm events such as tornados might be affected by climate change but scientists are not currently able to make accurate predictions because the storms are below the resolution of general circulation models. Windstorm events, and changes among them, are relevant to forest ecosystems because of their significant effects on tree density, canopy disruption, and tree mortality (Dale *et al.*, 2001).

Ice storms can occur anywhere in Canada and most of the United States but are most prevalent in northeastern US and Canada. Ice storms affect trees in differing severity, from breaking a few branches, to bending limbs, to canopy loss and stem breakage. Recently thinned stands are vulnerable due to the spread of the canopy layer before stems have enough strength to resist ice damage (Dale *et al.*, 2001). Ice storm damage is currently exhibited as stunted trees with deformed crowns in higher elevation forests in Nova Scotia (Neily *et al.*, 2003). It is unclear how climate change will affect ice storms, but their occurrence will likely shift in response to global warming (Dale *et al.*, 2001).

Landslides are the movement of soil, rock, and vegetation and will increase in frequency in areas where precipitation and storminess increase, and decrease in areas where precipitation decreases. Landslides result in extensive forest damage with the removal of soil and vegetation on steep slopes and damage to the forest floor where soil and vegetation settles (Dale *et al.*, 2001). Landslides are currently most common on the steep slopes of the Cape Breton Highlands EcoDistrict (Wahl *et al.*, 2002).

Other unfavourable effects on forests:

Although the extension of a frost-free period increases the length of growing season for softwood species, it could be detrimental to the growth of hardwoods. Damage to buds and roots may occur after they have dehardened if refreezing occurs. Birch, aspen, and maple are expected to be most vulnerable. (Zhu *et al.*, 2002; Environment Canada, 1999). Warmer winters and less snow cover might alter interactions among species (i.e. if deer populations increase, this might

lead to increased stress on regenerating trees from higher numbers of deer browsing). Changes in competition may alter plant populations from delays in flowering and changes in leaf structure and plant metabolism (Environment Canada, 1999).

Positive effects of climate change on forests:

Not all consequences of climate change are detrimental to forest ecosystems. A lengthened growing season might result in higher growth rates and productivity. Conifers (black spruce specifically) are expected to do well in a warmer environment as long as water resources remain accessible (Pollard, 1989; Environment Canada, 1999; Papadopol, 2000). The model projections, as explained in the previous section, indicate that increases in mean temperature and annual precipitation are expected for Nova Scotia (Hadley Centre, 2000; Environment Canada, 2000). Increased atmospheric CO_2 enhances nitrogen fixation, micorrhizal activity, biomass accumulation, and reduces transpiration thereby increasing water efficiency and enhancing photosynthesis (Pollard, 1989; Papadopol, 2000). Warmer soils lead to accelerated nutrient cycling and increased nutrient availability (Environment Canada, 1999). More research is required to develop strategies on CO_2 re-sequestration and species specific biomass production in response to increased CO_2 levels.

The Kyoto Protocol and Canada's Commitment to Emissions Reduction:

In 1992, Canada, along with more than 180 other countries, signed the United Nations Framework Convention on Climate Change (UNFCCC). This agreement came into effect in 1994 in response to climate change concerns and greenhouse gas emissions (Environment Canada, 2002). Participation in the agreement was not legally binding and little action was taken globally; therefore the Kyoto Protocol of 1997 was created. Canada agreed to an emissions target that aims to reduce annual average emissions to 6% below 1990 levels by 2008-2012. Greenhouse gas emissions in Canada are increasing and are now 19.6% higher than they were in 1990 and it is estimated that emissions will be 33% higher by 2010 if no action is taken. Canada ratified the Kyoto protocol in 2002, which will come into force when it has been ratified by 55 nations that represent at least 55% of industrial countries' CO_2 emissions in 1990. Canada's greenhouse gas emissions are expected to rise to 809 million tonnes by 2010, according to the business as usual scenario. Canada's goal, according to the Kyoto agreement, is 571 million tonnes, a difference of 240 million tonnes that must be dealt with. The imbalance in emissions reduction targets between Canada and the United States (who did not ratify the Kyoto Protocol) raises issues of competitiveness and Canada's plan must address this issue to receive endorsement from all

sectors. Canada is the only member of NAFTA (North American Free Trade Agreement) who has ratified the Kyoto Protocol (Environment Canada, 2002).

Carbon Sequestration and Storage in Forests to Slow the Effects of Climate Change:

Fossil fuels (oil and coal) contain permanently stored carbon (Papadopol, 2000). Oil and coal are not renewable resources and the carbon they release cannot be re-sequestered by fossil fuels and once released, can only be stored in the future in soil, biomass, and oceans. These carbon sinks are a transient form of carbon storage, unlike the permanent storage in fossil fuels (Papadopol, 2000). The soil has a tremendous capacity for carbon storage but is only effective as a carbon sink when shaded by overstory vegetation. This is because exposed soil heats up and decomposition occurs, switching the CO_2 balance from positive to negative (Papadopol, 2000).

The Fluxnet-Canada research network is examining the roles of Canadian forest ecosystems in the global carbon cycle. Canadian forests naturally release and absorb massive amounts of CO_2 - an amount that is fifteen times greater than emissions from manmade sources (Fluxnet-Canada, 2003). Researchers are studying the impacts of climate change, forest management practices, and natural disturbances on the carbon balance and the effectiveness of biomass and soils for sequestering atmospheric CO_2. There are seven forest flux measuring stations in Canada. The closest station to Nova Scotia is in a balsam fir (*Abies balsamea*) stand in New Brunswick (Fluxnet-Canada, 2003).

Preventing and slowing the effects of climate change is an important step in protecting natural resources as well as ourselves. The forest industry can play a significant role in these endeavors. Increasing the Earth's CO_2 sink capacity is one way to slow the effects of greenhouse gases in the atmosphere (Papadopol, 2000; Parker *et al.*, 2000; Pollard, 1989). Globally, deforestation during the last 50 years for agricultural use has greatly reduced the amount of forest available to store and sequester carbon (Papadopol, 2000). Deforestation has contributed to global warming by reducing the amount of carbon that is directly stored in the forest biomass and by soil exposure to the sun, which contributes to the decomposition and release of carbon as the soil is heated. Most of the carbon stored globally in forest vegetation exists in tropical forests. These are being deforested and harvested at a high rate, giving rise to a net carbon source equivalent to one-third the emissions from combustion of fossil fuels (Brown, 1996). Globally, there are up to 700 million ha of land available for carbon sequestration by slowing deforestation and encouraging regeneration. Forests in the tropical climate zone have the potential to sequester the most carbon (80%), with the temperate zone (17%) and the boreal zone (3%) less significant contributors. The temperate forests in Canada (which includes Nova Scotia) have limited potential for significant global CO_2 sequestration (4% of the total sequestration in temperate forests around

the world). Once the forest finishes growing, sequestration diminishes and storage capacity has reached its peak, but if harvested, immediate renewal will begin the sequestration process again. Harvesting at appropriate rotation lengths can maximize the amount of CO_2 being sequestered from the atmosphere and stored in the forest (Brown, 1996). Following this, it might take some time before mitigation efforts are observed due to the large buffering capacity of the Earth's size (Papadopol, 2000).

Forest Ecosystem Management Options for Nova Scotia:

Due to the uncertainty surrounding the extent of climate change and regional effects that will be experienced in Nova Scotia, researchers and people in the forest industry must remain flexible to changing management strategies for climate change adaptation as more information becomes available. The National Forest Strategy now includes climate change in its list of priorities for sustainable forest management. Incorporated into forest policy and forest management planning will be knowledge of climate change effects and the Kyoto Protocol (Canadian Council of Forest Ministers, 2003). Forest management has a large impact on growth, health, and composition, and managed forests are generally less vulnerable to the impacts of climate change (Natural Resources Canada, 2002). If one can adapt and adjust appropriately to the effects of climate change, new opportunities might become available (i.e. faster-growing species, different species distributions, etc.) (Government of Canada, 2001; Canadian Forest Service, 1999). The following recommendations are intended to prepare us for climate change and contribute to the reduction of CO_2 in the atmosphere and will benefit forestry whether the predicted effects of climate change are realized or not.

What can be done to help reduce CO_2 by promoting forest sinks:

- Intensive forest management can increase productivity (and therefore carbon storage capabilities) (Papadopol, 2000; Parker *et al.*, 2000). Development of intensive management can increase growth and shorten rotation times. Management that includes assisted regeneration and tree planting, vegetation management, and use of fertilization on some types of soils can increase a forest's potential to sequester and store carbon by increasing productivity and shortening rotation times. The intensity of harvesting influences the carbon balance in the forest. Clearcutting removes the most amount of carbon per unit area at a given time. Selection or partial cutting removes less carbon than clearcutting at a given time, but does so more frequently, leaving a continual amount of growing biomass in the forest. Selection cutting reduces the exposure of the soil to the sun, thereby ensuring a positive CO_2 balance in the soil, promoting carbon storage and uptake (Papadopol, 2000). Harvesting often results in long-term carbon storage in durable wood products.

- Reforestation and tree planting programs to increase stocking in clearcut areas and intensive silviculture to boost growth and yield of growing forests are practical ways to sequester atmospheric CO_2 (Papadopol, 2000; Parker *et al.*, 2000). Short rotation forestry has been recommended by Parker *et al.* (2000) using fast-growing hardwoods to optimize the amount of CO_2 that will be stored. Since Canada will play a relatively small role in global sequestration of carbon (Brown, 1996) and there are climatic and site limitations to growth rates, efforts could be concentrated so that forests are not a net source locally.

- Enhancing forest monitoring programs to prepare for disturbances and enhance growth following disturbances (such as fire, blowdown, and insect or disease damage) is necessary and mitigating against these disturbances will help reduce the amount of CO_2 being added to the atmosphere (Papadopol, 2000; Parker *et al.*, 2000; Natural Resources Canada, 2002; Environment Canada, 1999; Dale *et al.*, 2001). Monitoring programs might reveal short-term and long-term changes that are happening and adaptation techniques can then be evaluated.

What can be done to prepare for ecological change to make forests resilient and protect biodiversity:

- Conservation of biodiversity is a valuable strategy for protecting forests from the effects of climate change and requires an ecosystem management type approach. Biodiversity should be conserved at three levels: ecosystems (i.e. protection of rare ecosystems such as old growth forests or rare vegetation associations), species (especially those native to Nova Scotia), and genes (genetic management) (Parker *et al.*, 2000). Maintaining and enhancing genetic diversity will allow each species to persist over larger ranges of latitude, increasing the adaptability of each species to climate change (Papadopol, 2000). This can be achieved by promoting structural and compositional diversity in the forest, which also increases the diversity of wildlife niches that are available. Ex situ strategies for enhancing and protecting genetic diversity might be an appropriate tool in preparation for the future (Parker *et al.*, 2000). These strategies might include species that currently exist in Nova Scotia as well as others that are expected to do well in a warmer climate. The conservation of ecosystem biodiversity can be achieved by promoting regeneration and by matching tree species to appropriate site conditions (with the assistance of a Forest Ecosystem Classification (FEC) and Ecological Land Classification (ELC)).

- To reduce the vulnerability of trees to drought in Nova Scotia, where a slight decrease in precipitation levels and an increase in temperature during the growing season (March to August) can be expected (Table 3), periodic thinning to reduce moisture stress on the remaining trees was recommended by Papadopol (2000).

- Except for instances where fire is ecologically significant, it is important to enhance fire prevention and suppression activity to prevent the loss of forest cover over soils (CO_2 sinks) and to prevent the release of added CO_2 into the atmosphere.

- Close monitoring and mitigation efforts on insect infestations and diseases as they approach Nova Scotia or grow in population within Nova Scotia, possibly from opportunistic insects or pathogens presenting themselves due to changes in temperature, should be considered for conserving biodiversity (Papadopol, 2000; Parker *et al.*, 2000; Natural Resources Canada, 2002; Environment Canada, 1999; Dale *et al.*, 2001).

- To prepare for increased forest disturbances, pre-disturbance management techniques include the altering of forest structure and composition to reduce vulnerability. A better understanding is required of how silviculture practices increase or decrease susceptibility to disturbances. Increased pest and fire management might be necessary to control disturbance agents, while harvesting and tending can remove susceptible crops. Recovery techniques following disturbance include enhancement of regeneration, planting of resilient species and species mixes, and salvaging dying stands to promote the health of the residual forest (Canadian Forest Service, 1999; Dale *et al.*, 2001).

- Modifying wood supply models should be considered to investigate potential effects of changing species performances. Applying current silvics knowledge to downscaled climate models (Lines, 2003) - similar to the research of Prasad and Iverson (1999-ongoing) - will allow a spacial projection of optimal habitat for individual tree species under climate change scenarios. Managers can use this information to improve species selections and understand how species are linked together and represented in 'the big picture'.

Other mitigation methods will be added as research at the regional level becomes more precise. Migration of species into Nova Scotia is particularly difficult due to the unique geography of the province, so increased knowledge of invasion ecology should be developed further for use in assisting migration. As models become more precise and fine-tuned, mitigation efforts can be applied with more confidence. Modeling distributions of native species responses to predicted climate regimes based on silvics knowledge (within ecosystem and biophysical units) should be developed further for Nova Scotia as it has for the Eastern United States (Prasad and Iverson, 1999-ongoing). Presently, efforts should focus on reducing greenhouse gas emissions, protecting biodiversity, and maintaining and extending CO_2 sinks.

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